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(54) **Equipment for Drilling a Hole in Underground Formations and Downhole Motor Adapted to Form Part of Such Equipment**

(57) A downhole motor (such as a turbodrill) having the main parts thereof made of non-magnetizable material is mounted in drilling equipment for drilling a borehole in subsurface formations. A directional surveying instrument is placed in a non-magnetic drill collar section above the downhole motor

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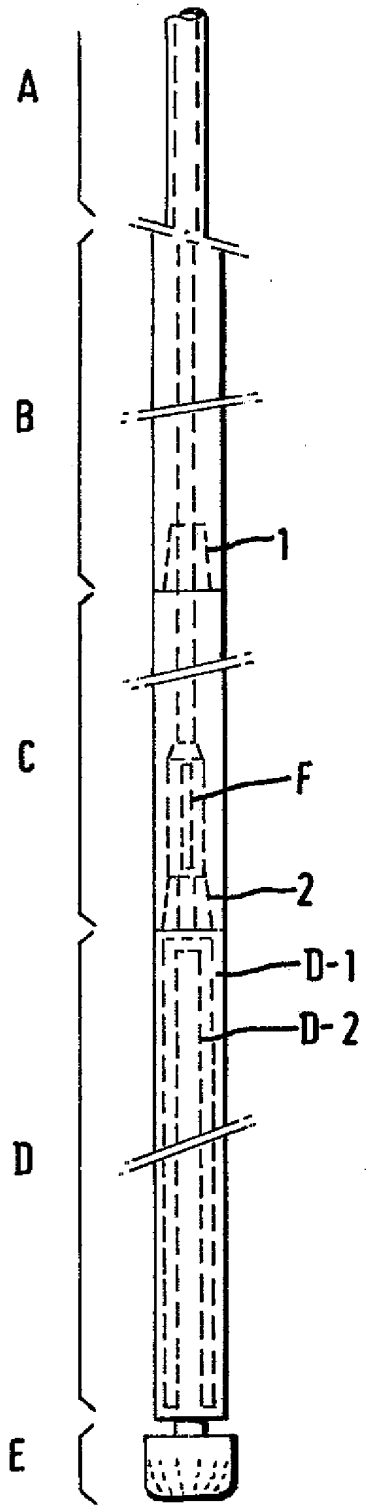
A
B
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SPECIFICATION

Equipment for Drilling a Hole in Underground Formations and Downhole Motor Adapted to Form Part of Such Equipment

The invention relates to equipment for drilling a hole in underground formations. Such holes may be exploratory wells for exploring the formations for the presence of valuable materials, such as oil, gas, salts, coal and minerals. Also, such holes may be used as wells in processes for recovering valuable materials from underground formations.

The invention further relates to a downhole motor adapted to form part of such equipment.

In particular, the present invention relates to drilling equipment including a surveying instrument by means of which the extent and direction of departure of the borehole from a true vertical condition can be determined during the drilling operation. The surveying instrument includes means for determining at each point of the central axis of the borehole the inclination of the hole as well as the azimuth thereof. In the present specification and claims, the expression "inclination" indicates the angle between the central axis of the hole and the vertical, whereas the expression "azimuth" indicates the angle between the North and the projection of the borehole axis on the horizontal plane. Thus, the direction of the borehole at each level can be determined by measuring the inclination and the azimuth of the hole at that level.

More particularly, the present invention relates to drilling equipment including a surveying instrument wherein the means for determining the azimuth comprises magnetically sensitive elements, such as a magnetic compass or a plurality of magnetometers or fluxgates. The surveying instrument may either be mounted in the drilling equipment during the whole period of the drilling operation, or be lowered to a predetermined location in the equipment during the halting of the actual drilling action of the equipment.

Since the material of the drill string is found to be magnetized in normal use of the drilling equipment, the string is provided with a lower section consisting of one or more drill collars of non-magnetic material. This non-magnetic drill collar section is connected at the lower end thereof to a drill bit. If required, various subs, such as a circulating sub, one or more stabilising subs, or a bent sub, may be mounted between the bit and the lower end of the non-magnetic drill collar section. The surveying instrument is located at a level in the non-magnetic drill collar section, where the magnetic influence of the magnetic upper section of the drill string as well as the magnetic influence of the bit and the sub(s) has a minimum value. An appreciable disturbance of the magnetically sensitive elements of the surveying apparatus is thereby obviated.

It will be appreciated that the main components of the surveying instrument, such as the housing thereof, are also made of non-magnetic material.

For drilling operations wherein the borehole should be drilled in a particular direction (which may be either in the direction of the true vertical, or in any other desired direction), a hydraulic downhole motor, such as a hydraulic turbine is often mounted between the lower end of the drill string and the drill bit. Subs may be mounted between the motor and the bit. The hydraulic motor is driven by high-pressure drilling fluid that is passed down to the drill bit via the drill string. Apart from hydraulic turbines (also referred to as turbodrills), other types of hydraulic motors such as vane or roller type hydraulic motors, or Moineau type fluid motors may be applied for actuating the drill bit.

In order that timely action can be taken to steer the bit driven by the downhole hydraulic motor in a predetermined desired direction, the drill string is provided with a lower section consisting of one or more non-magnetic drill collars, and a surveying instrument that is adapted amongst others to measure the azimuth of the borehole by magnetically sensitive elements is positioned in the said lower end of the drill string. The magnetic flux of the downhole motor is estimated to be in the same order of magnitude as the magnetic flux of a drill collar section of a length equal to the length of the downhole motor, and the length of the non-magnetic lower section of the drill collar and the level therein at which the surveying instrument is located is chosen such that the flux density at that location is sufficiently small to allow undisturbed or approximately indisturbed azimuth-measurements to be taken by the magnetically sensitive elements of the surveying instrument.

Although applicant as well as anybody else engaged in directional drilling operations by means of downhole motors are using the above described drilling equipment over the last ten to fifteen years, applicant has only recently found that the measuring results obtainable by the surveying instruments mounted in the non-magnetic drill collar section are not reliable, and that the measured azimuth values of the borehole directions often vary from the actual values thereof to an unacceptable extent.

The object of the invention is to remove the above-mentioned drawback. More accurate information on the direction of the central axis of the drill bit and the course of the drilled hole in the subsurface formations will allow the drilling operator to reach the desired target in a more efficient manner than could be done up till now. Also, the chances of drilling boreholes into existing wells will become smaller, which will increase the safety of the drilling operations.

The equipment according to the invention for drilling a hole in underground formations includes a drill string having the lower section thereof consisting of one or more drill collars of non-magnetic material, said lower section being connected at the lower end thereof to a downhole

hydraulic motor with a drilling bit adapted to be actuated by the motor, the motor having at least one of the main components thereof made of non-magnetic material, and a surveying instrument including magnetically sensitive elements positioned in the lower section of the drill string.

Moreover, the invention is directed to a downhole hydraulic motor having at least one of the main components thereof made of non-magnetic material.

It has been found by applicant, that hydraulic downhole motors, such as hydraulic turbines (also referred to as turbodrills) made of magnetizable material were magnetized during use thereof to a far greater extent than was expected. As mentioned already hereinbefore, the value of the magnetic flux of a downhole motor in operation in a borehole was up till now assumed to be of the same order of magnitude as the magnetic flux of a magnetic drill collar (about 1000 microweber) being used in the same borehole, Applicant, however, found that—although this might be true over the initial use period of a new drill collar and a new turbine—the value of the magnetic flux of the turbine will grow above the value of the magnetic flux of the drill collar during prolonged use thereof, and may rise to values up to 4000 microweber. As a consequence of this increase of the magnetic flux of the downhole motor the flux density at the location of the surveying instrument in the non-magnetic drill collar section will grow to a value at which the results of the measurements taken by the surveying instrument will no longer correlate with the actual azimuth of the borehole, which latter will then run astray. This may lead to drilling of the hole into existing wells, or to a dry hole when the hole does not reach the required target.

Applicant has as yet made no attempts to explain the above-mentioned phenomenon of increase of the overall magnetization of a downhole motor in use in a borehole, but it is surmised that the relatively high stress pattern in material of a downhole motor under operating conditions may be indicated as the cause of this phenomenon.

It will be appreciated that by using non-magnetic material for the manufacture of at least the main components of the hydraulic downhole motor to be used in the drilling equipment according to the invention, there is no need to increase the number of drill collars of non-magnetic material that form the lower section of the drill string in order to bring the surveying instrument substantially outside the magnetic field of the downhole motor. Increasing the length of the non-magnetic drill collar section would undoubtedly render the measurements taken by the surveying instrument more accurate if a conventional downhole motor was used, but, since the distance between the surveying instrument and the bit would be increased as well, the correlation between the measured values of the azimuth and the actual values of the azimuth of the hole at the level of the drill bit would become unreliable.

Application of the present invention allows the surveying instrument to be placed directly above the downhole motor, and consequently as close as possible to the drill bit, thereby obviating the above disadvantage. Moreover, the measuring results will be more accurate than obtainable by the drilling equipment including a downhole motor made of magnetic materials.

It is observed that by the expression "magnetic material", there is to be understood material that is either magnetic, or magnetizable (that is will become magnetized when exposed to a magnetic field).

The expression "non-magnetic material" is used in relation to material that is non-magnetic, and that will not become magnetic to an unallowable extent when exposed to a magnetic field.

The expression "main component" of the downhole motor refers to those components that are made of metal and extend substantially in the direction of the central axis of the hydraulic downhole motor. These components, such as the housing and the central shaft of the motor, if made of magnetizable material, will, when the downhole motor is operating in a borehole, be liable to a large extent to magnetization, whereby a magnetic field is induced in this material, which field will disturb the correct operation of surveying instrument.

The invention will now be described by way of example in more detail with reference to the drawing which schematically shows a side view of drilling equipment according to the invention, this equipment including a turbodrill.

The drilling equipment consists of the main parts A—F.

Part A is the main part of the drill string, and consists of a plurality of drill pipes of magnetized material.

Part B is that part of the drill string that consists of a plurality of drill collars of magnetized material.

Part C is the lower section of the drill string, which section consists of a limited number of drill collars (such as between one and three drill collars) that are made of non-magnetic material.

Part D is a tubodrill, having the main components thereof (the housing D—1 and the central shaft D—2) made of non-magnetic material.

Part E is a diamond bit, having a metal body made of magnetized material.

Part F is a directional surveying instrument for taking measurements of the orientation of the central axis thereof, said instrument including magnetically sensitive elements for measuring the earth's magnetic field.

The adjoining drill pipes of the part A of the drilling equipment shown in the drawing are interconnected in a manner known per se (such as by not-shown screw couplings). The same applies for the drill collars of parts B and D.

Parts B and C, and parts C and D are interconnected by the screw couplings 1 and 2, respectively.

The bit E is connected to the shaft D—2 of the turbodrill D in a suitable known manner (not shown).

The directional surveying instrument F may be any instrument suitable for the purpose, such as the instrument described in USA patent specification No 3,791,043 (Inventor M. K. Russell; filed 9th June, 1971; granted 12th February, 1974) The instrument F is mounted in a suitable known manner in the lower end of the lowermost of the non-magnetic drill collars of the part C of the drilling equipment. Transmission of the signals representing the values measured by the instrument F takes place to the surface through not-shown electric conduits arranged through the drill collars and drill pipes in a suitable known manner, such as the manner described in British patent specification No. 1,055,061 (Inventors E. B. Denison, L. L. Dickson, G. L. Marsh; filed 29th September, 1977; published 8th August, 1979).

A fluid passage is provided in the drilling equipment, said passage extending through the drill pipes of part A, the drill collars of part B, the drill collars of part C (thereby passing alongside the instrument F), between the (not shown) turbine blades present in the annular space between the housing D—1 and the central shaft D—2 of the turbodrill D, and finally through (not shown) channels and nozzles arranged in the bit E.

Drilling fluid that is pumped down through the drilling equipment of the drawing (when in an operative position in a borehole) passes along the (not shown) blades of the hydraulic turbine D, which turbine drives the bit E, thereby deepening the hole. Periodically, the drilling action is halted to lengthen the part A of the drill string by adding an additional drill pipe to the top thereof. Before resuming the drilling action, a measurement is taken by the surveying instrument F to determine the direction of the central axis of this equipment (and of the lower end of the part C of the drill string). Since the surveying instrument F is mounted as close as possible to the bit E, information on the direction of the central axis of the borehole at the level of the bit is obtained as accurately as possible. Measures known per se can then be taken to steer the turbine/bit combination in another direction, if this is considered desirable. A plurality of means and methods are known per se for performing such a steering operation. If these means include equipment that should be mounted between the parts C and D of the drilling equipment, such steering equipment should be made of non-magnetic material.

In an alternative manner of operation, the signals raised by the instrument F are continuously relayed to the drilling flow such that the tool pusher is informed of each moment of the direction of the lower end of the hole during the actual drilling operation.

It will be appreciated that although the example shown in the drawing has both the housing D—1 and the central shaft D—2 made of non-magnetic material, the invention can also be used with good results in other situations with only one of these components made of non-magnetic material. In another embodiment, at least one of the main components D—1 and D—2 may be made of non-magnetic material in combination with other components of the turbine, such as the blades and/or the bearings or part of the bearings.

The downhole motor according to the invention may consist of several sections that are interconnected by coupling means. Such sectionalized construction is often applied for high-power motors.

Various types of non-magnetic materials may be used in the equipment according to the present invention. Reference is made to the book "Der nicht-magnetisierbare Stahl und seine Anwendung" (The non-magnetizable steel and its use by Dr. Peter Bluhm (R. v. Decker's Verlag G. Schenck; Hamburg-Berlin 1967) describing such materials. Depending the particular conditions under which the hydraulic downhole motors will have to operate, a suitable choice of non-magnetic material for this purpose can easily be made.

Finally, it is observed that the equipment according to the invention may include any other type of downhole motor and/or drilling bit than those shown in the drawing.

Claims

1. Equipment for drilling a hole in underground formations, said equipment including a drill string having the lower section thereof consisting of one or more drill collars of non-magnetic material, said lower section being connected at the lower end thereof to a downhole hydraulic motor with a drilling bit adapted to be actuated by the motor, the motor having at least one of the main components thereof made of non-magnetic material, and a surveying instrument including magnetically sensitive elements positioned in the lower section of the drill string.

2. Equipment according to claim 1, wherein the hydraulic downhole motor is constituted by a turbine.

3. Equipment according to claim 1 or 2, wherein the surveying instrument is mounted in the lower part of the lower section of the drill string.

4. Equipment for drilling a hole in underground formations, substantially as described in the specification with reference to the drawing.

5. Hydraulic downhole motor for use in drilling a hole in underground formations, the motor having at least one of the main components thereof made of non-magnetic material.

6. Hydraulic downhole motor according to claim 5, the motor being constituted by a hydraulic turbine

7. Hydraulic downhole motor according to claim 6, consisting of a sectionalized hydraulic turbine.

8. Hydraulic downhole motor for drilling a hole in underground formations substantially as described in the specification with reference to the drawing.

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